Biased Phase Sweep Transmit Diversity

Related Application

Related subject matter is disclosed in the following applications filed concurrently and assigned to the same assignee hereof: U.S. Patent Application Serial No. ______________ entitled, "Space Time Spreading and Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer, Robert Atmaram Soni and Paul A Polakos; U.S. Patent Application Serial No. ______________ entitled, "Symmetric Sweep Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer, Paul A Polakos and Mark Kraml; U.S. Patent Application Serial No. ______________ entitled, "Split Shift Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer, Robert Atmaram Soni and Paul A Polakos.

Background of the Related Art

Performance of wireless communication systems is directly related to signal strength statistics of received signals. Third generation wireless communication systems utilize transmit diversity techniques for downlink transmissions (i.e., communication link from a base station to a mobile-station) in order to improve received signal strength statistics and, thus, performance. Two such transmit diversity techniques are space time spreading (STS) and phase sweep transmit diversity (PSTD).

FIG. 1 depicts a wireless communication system 10 employing STS. Wireless communication system 10 comprises at least one base station 12 having two antenna elements 14-1 and 14-2, wherein antenna elements 14-1 and 14-2 are spaced far apart for achieving transmit diversity. Base station 12 receives a signal S for transmitting to mobile-station 16. Signal S is alternately divided into signals s_e and s_o, wherein signal s_e comprises even data bits and signal s_o comprises odd data bits. Signals s_e and s_o are processed to produce signals S^{14-1} and S^{14-2}. Specifically, s_e is multiplied with Walsh code w_1 to produce signal $s_e w_1$; a conjugate of signal s_o is multiplied with Walsh code w_2 to produce signal $s_o{}^*w_2$; signal s_o is multiplied with Walsh code w_1 to produce $s_o w_1$; and a conjugate of signal s_e is multiplied with Walsh code w_2 to produce $s_e{}^*w_2$. Signal $s_e w_1$ is added to signal $s_o{}^*w_2$ to produce signal S^{14-1} (i.e., $S^{14-1}=s_e w_1+s_o{}^*w_2$) and signal $s_e{}^*w_2$ is subtracted from signal $s_o w_1$ to produce signal S^{14-2} (i.e., $S^{14-2}=s_o w_1-s_e{}^*w_2$). Signals S^{14-1} and S^{14-2} are transmitted at substantially equal or identical power levels over antenna elements 14-1 and 14-2, respectively. For purposes of this application, power levels are "substantially equal" or "identical" when the power levels are within 1% of each other.

Mobile-station 16 receives signal R comprising $\gamma_1(S^{14-2})+\gamma_2(S^{14-2})$, wherein γ_1 and γ_2 are distortion factor coefficients associated with the transmission of signals S^{14-1} and S^{14-2} from antenna elements 14-1 and 14-2 to mobile-station 16, respectively. Distortion factor coefficients γ_1 and γ_2 can be estimated using pilot signals, as is well-known in the art. Mobile-station 16 decodes signal R with Walsh codes w_1 and w_2 to respectively produce outputs:

$$W_1=\gamma_1 s_e+\gamma_2 s_o \quad \text{equation 1}$$

$$W_2=\gamma_1 s_o^*-\gamma_2 s_e^* \quad \text{equation 1a}$$

Using the following equations, estimates of signals s_e and s_o, i.e., $\hat{s}_e$ and $\hat{s}_o$, may be obtained:

$$\hat{s}_e = \gamma_1^* W_1 - \gamma_2 W_2^* = s_e\left(|\gamma_1|^2 + |\gamma_2|^2\right) + noise \quad \text{equation 2}$$

$$\hat{s}_o = \gamma_2^* W_1 + \gamma_1 W_2^* = s_o\left(|\gamma_1|^2 + |\gamma_2|^2\right) + noise' \quad \text{equation 2a}$$

However, STS is a transmit diversity technique that is not backward compatible from the perspective of the mobile-station. That is, mobile-station 16 is required to have the necessary hardware and/or software to decode signal R. Mobile-stations without such hardware and/or software, such as pre-third generation mobile-stations, would be incapable of decoding signal R.

By contrast, phase sweep transmit diversity (PSTD) is backward compatible from the perspective of the mobile-station. FIG. 2 depicts a wireless communication system 20 employing PSTD. Wireless communication system 20 comprises at least one base station 22 having two antenna elements 24-1 and 24-2, wherein antenna elements 24-1 and 24-2 are spaced far apart for achieving transmit diversity. Base station 22 receives a signal S for transmitting to mobile-station 26. Signal S is evenly power split into signals s_1 and s_2 and processed to produce signals S^{24-1} and S^{24-2}, where $s_1=s_2$. Specifically, signal s_1 is multiplied by Walsh code w_k to produce $S^{24-1}=s_1 w_k$, where k represents a particular user or mobile-station. Signal s_2 is multiplied by Walsh code w_k and a phase sweep frequency signal $e^{j2\pi f_s t}$ to produce S^{24-2}, i.e., $S^{24-2}=s_2 w_k e^{j2\pi f_s t} = s_1 w_k e^{j2\pi f_s t} = S^{24-1} e^{j2\pi f_s t}$, where f_s is a phase sweep frequency and t is time. Signals S^{24-1} and S^{24-2} are transmitted at substantially equal power levels over antenna elements 24-1 and 24-2, respectively. Note that the phase sweep signal $e^{j2\pi f_s t}$ is being represented in complex baseband notation, i.e., $e^{j2\pi f_s t} = \cos(2\pi f_s t)+j\sin(2\pi f_s t)$. It should be understood that the phase sweep signal may also be applied at an intermediate frequency or a radio frequency.

Mobile-station 26 receives signal R comprising $\gamma_1 S^{24-1}+\gamma_2 S^{24-2}$. Simplifying the equation for R results in

$$R = \gamma_1 S^{24-1} + \gamma_2 S^{24-1} e^{j2\pi f_s t} \qquad \text{equation 3}$$

$$R = S^{24-1}\left\{\gamma_1 + \gamma_2 e^{j2\pi f_s t}\right\} \qquad \text{equation 3a}$$

$$R = S^{24-1}\gamma_{eq} \qquad \text{equation 3b}$$

where γ_{eq} is an equivalent channel seen by mobile-station 26. Distortion factor coefficient γ_{eq} can be estimated using pilot signals and used, along with equation 3b, to obtain estimates of signal s_1 and/or s_2.

In slow fading channel conditions, PSTD improves performance (relative to when no transmit diversity technique is used) by making the received signal strength statistics associated with a slow fading channel at the receiver look like those associated with a fast fading channel. However, in additive white gaussan noise (AWGN) conditions, PSTD can significantly degrade performance. Accordingly, there exists a need for a transmit diversity technique that is backward compatible without significantly degrading performance in AGWN conditions.

Summary of the Invention

The present invention is a method and apparatus of transmit diversity that is backward compatible and does not significantly degrade performance in additive white guassan noise (AWGN) conditions using a transmission architecture that incorporates a form of phase sweep transmit diversity (PSTD) referred to herein as biased PSTD. Biased PSTD involves transmitting a signal and a frequency swept version of the same signal over diversity antennas at different power levels. By transmitting the two signals at different power levels, the depths of nulls normally seen in AWGN conditions when PSTD is utilized is reduced and performance degradation in AWGN conditions is mitigated.

Brief Description of the Drawings

The features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where

FIG. 1 depicts a wireless communication system employing space time spreading techniques in accordance with the prior art;

FIG. 2 depicts a wireless communication system employing phase sweep transmit diversity in accordance with the prior art; and

FIG. 3 depicts a base station employing code division multiple access (CDMA) and a form of phase sweep transmit diversity (PSTD) referred to herein as biased PSTD in accordance with the present invention.

Detailed Description

FIG. 3 depicts a base station 30 employing code division multiple access (CDMA) and a form of phase sweep transmit diversity (PSTD) referred to herein as biased PSTD in accordance with the present invention. Biased PSTD involves transmitting a signal and a frequency swept version of the same signal over diversity antennas at different power levels to reduce the depths of nulls. Advantageously, biased PSTD is backwards compatible from the perspective of mobile-stations and does not degrade performance as much as PSTD in additive white gaussan noise (AWGN) conditions. CDMA is well-known in the art.

Base station 30 provides wireless communication services to mobile-stations, not shown, in its associated geographical coverage area or cell, wherein the cell is divided into three sectors α, β, γ. Base station 30 includes a transmission architecture that biased PSTD, as will be described herein.

Base station 30 comprises a processor 32, a splitter 34, multipliers 36, 38, amplifiers 44, 46, and a pair of diversity antennas 48, 50. Note that base station 30 also includes configurations of splitters, multipliers, amplifiers and antennas for sectors β, γ that are identical to those for sector α. For simplicity sake, the configurations for sectors β, γ are not shown. Additionally, for discussion purposes, it is assumed that signals S_k are intended for mobile-stations k located in sector α and, thus, the present invention will be described with reference to signals S_k being processed for transmission over sector α.

Processor 32 includes software for processing signals S_k in accordance with well-known CDMA techniques to produce an output signal $S_{k\text{-}1}$. Note that, in another embodiment, processor 32 is operable to process signals S_k in accordance with a multiple access technique other than CDMA, such as time or frequency division multiple access.

Signal $S_{k\text{-}1}$ is split by splitter 34 into signals $S_{k\text{-}1}(a)$, $S_{k\text{-}1}(b)$ and processed along paths A and B, respectively, by multipliers 36, 38, and amplifiers 44, 46 in accordance with bias PSTD techniques, wherein signal $S_{k\text{-}1}(a)$ is identical to signal $S_{k\text{-}1}(b)$ in terms of data. In one embodiment, signal $S_{k\text{-}1}$ is unevenly power split by splitter 34 such that the power level of signal $S_{k\text{-}1}(a)$ is higher than the power level of signal $S_{k\text{-}1}(b)$. For example, signal $S_{k\text{-}1}$ is power split such that signal $S_{k\text{-}1}(a)$ gets 5/8 of signal $S_{k\text{-}1}$'s power and signal $S_{k\text{-}1}(b)$ gets 3/8 of signal $S_{k\text{-}1}$'s power,

i.e., $S_{k-1}(a)=\sqrt{5/8}\,(S_{k-1})$ and $S_{k-1}(b)=\sqrt{3/8}\,(S_{k-1})$. In another example, signal S_{k-1} is power split such that signal $S_{k-1}(a)$ gets 2/3 of signal S_{k-1}'s power and signal $S_{k-1}(b)$ gets 1/3 of signal S_{k-1}'s power. In one embodiment, signal S_{k-1} is unevenly power split by splitter 34 such that the power level of signal $S_{k-1}(b)$ is higher than the power level of signal $S_{k-1}(a)$, or signal S_{k-1} is evenly power split into signals $S_{k-1}(a)$, $S_{k-1}(b)$. Signal $S_{k-1}(a)$ and carrier signal $e^{j2\pi f_c t}$ are provided as inputs into multiplier 36 to produce signal S_{36}, where $S_{36}=S_{k-1}(a)e^{j2\pi f_c t}$, $e^{j2\pi f_c t}=\cos(2\pi f_c t)+j\sin(2\pi f_c t)$, f_c represents a carrier frequency and t represents time.

Signal $S_{k-1}(b)$, phase sweep frequency signal $e^{j\Theta_s(t)}$ and carrier signal $e^{j2\pi f_c t}$ are provided as inputs into multiplier 38 where signal $S_{k-1}(b)$ is frequency phase swept with signal $e^{j\Theta_s(t)}$ and modulated onto carrier signal $e^{j2\pi f_c t}$ to produce signal $S_{38}=S_{k-1}(b)e^{j2\pi f_c t}e^{j\Theta_s(t)}$, wherein $\Theta_s=2\pi f_s t$, $e^{j\Theta_s(t)}=\cos(2\pi f_s t)+j\sin(2\pi f_s t)$ and f_s represents a phase sweep frequency.

Signals S_{36}, S_{38} are amplified by amplifiers 44, 46 to produce signals S_{44} and S_{46} for transmission over antennas 48, 50, respectively, where signal $S_{44}=A_{44}\,S_{k-1}(a)e^{j2\pi f_c t}$, $S_{46}=A_{46}\,S_{k-1}(b)e^{j2\pi f_c t}e^{j\Theta_s(t)}$, A_{44} represents the amount of gain associated with amplifier 44 and A_{46} represents the amount of gain associated with amplifier 46.

In one embodiment, the amounts of gain A_{44}, A_{46} are equal. In this embodiment, signal S_{k-1} is split by splitter 34 such that the power level of signal $S_{k-1}(a)$ is higher than the power level of signal $S_{k-1}(b)$, or vice-versa, so that differences in power level between signals S_{44} and S_{46} are not as large compared to an even power split of signal S_{k-1}.

In another embodiment, the amounts of gain A_{44}, A_{46} are different and related to how splitter 34 power splits signal S_{k-1}. For example, the amount of gain A_{44}, A_{46} applied to signals S_{36}, S_{38} should be an amount that would cause the power levels of signals S_{44} and S_{46} to be approximately equal. For purposes of this application, power levels are "approximately equal" when the power levels are within 10% of each other. In another example, the signal, e.g., S_{36} or S_{38}, associated with a greater power level is amplified more than the other signal.

In the case where signal $s_{\alpha-1}$ and/or signals S_{36}, S_{40} are not biased or unevenly split or amplified, STS performance will degrade because signal S_{44} will be transmitted at approximately 1/3 of the power at which signal S_{46} will be transmitted. Advantageously, biasing or unevenly splitting signal $s_{\alpha-1}$ and/or biasing or unevenly amplifying signals S_{36}, S_{40} mitigates this degradation to STS performance relative to the case where neither signal $s_{\alpha-1}$ nor signals S_{36}, S_{40} are biased or unevenly split or amplified.

Although the present invention has been described in considerable detail with reference to certain embodiments, other versions are possible. Therefore, the spirit and scope of the present invention should not be limited to the description of the embodiments contained herein.